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JAN 78 J HEITZ, J MCCHESNEY DAAB07-77-C-0189
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Research and Development Technical Report

ECOM- 77-0189-1-A

VE~~C~~HICULAR INTERCOMMUNICATIONS SYSTEM

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FOREWORD

NEW

This first quarterly report on the Vehicular Communications System Study, Contract DAAB07-77-C-0189, is submitted 6 January 1978 for the period 29 October 1977 through 31 December 1977 by ITT Aerospace/Optical Division, 3700 E. Pontiac St., Fort Wayne, IN 46803. Technical Monitor is Mr. Glenn Williman, DRDCO-COM-RN-3. ITT-A/OD Report Number is 81100-TR-1.

This Technical Report has been reviewed and approved.

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1.0 INTRODUCTION

The objective of this contract is to study the various techniques (wireless communication, control signaling) which apply to a vehicular intercommunication system and then select a design approach that will provide an intercom system that is very reliable with good voice intelligibility and is simple to operate.

In order to have a clear understanding of operational needs, logistics support requirements and technical problems imposed by tactical secure voice operation, two technical meetings were held at ITT-A/OD and Ft. Monmouth.

- One was held at ITT-A/OD on October 18-19, 1977; the major topic was the Logistic Support Analysis (LSA) portion of the program. This meeting was attended by Glenn Williman and Bruce Balance of ECOM and J. Heitz and W. Sloan of ITT-A/OD.
- The second meeting was held at ECOM on November 17, 1977 to discuss the requirements of the Intercom System with the user and ECOM representatives. This meeting was attended by J. Heitz and J. Mc Chesney of ITT-A/OD.

As a result of these meetings information on the operational requirements for the intercom system was gathered. This information was combined with other data gathered by ITT-A/OD in analyzing AN/VIC-1 assets, solicitation DAAB-07-77-Q-0252 and previous ITT-A/OD proposal work, to develop detailed requirements for the intercom system. The results of this requirement analysis are presented in Section 2.0 of this quarterly report. The requirements for the intercom system are presented in four areas:

1. Configuration Requirements: The system configuration is established and control capability of each station (commander, crew, external) is defined.
2. EMC/TEMPEST: On the basis of documents received by ITT-A/OD at this time an assessment of EMC (MIL-STD-461) and TEMPEST (NACSEM5100) requirements have been made.

3. Electrical/Mechanical Design Requirements: General electrical and mechanical design guidelines were established. These will be expanded into definitive design specifications as the study progresses and results of breadboard tests are evaluated.

4. LSA Requirements: The LSA plan has been updated and the LSA model ADP program was requested and received. In addition, the LSA plan was updated to incorporate changes resulting from the LSA conference and the revised plan submitted to ECOM on 8 November 1977.

In addition to generating the above Intercom System requirements, work was also performed in evaluating technical approaches applicable to the intercom design. The work was performed in the following areas:

1. Wireless Communication: Heavy emphasis on analyzing wireless communication techniques was applied early in the study program to allow development time for the selected wireless approach. Four wireless techniques were considered: I.R., Microwave, Acoustic, and RF. The results of this analysis are presented in Section 3.1. These preliminary results indicate that UHF/FM is the best candidate to meet the operational requirements for wireless operation.

2. Signal Routing and Multiplexing Techniques: In accordance with analysis performed in the proposal, Time Division Multiplexing has been selected as one of the optimum approaches for routing signals between intercom stations. A TDM system design is presented in Section 3.2 which minimizes data bit rate versus previous proposal designs.

3. Control Techniques: A tradeoff analysis of discrete versus microprocessor control approaches is performed in Section 3.3. An integrated microprocessor control network is selected as the optimum approach. Preliminary technical details on implementation of a microprocessor based control network is presented.

Finally, Section 4.0 of this report covers in detail the work which will be performed in the second reporting period of this study contract.

2.0 INTERCOM SYSTEM REQUIREMENTS

The following subsections present a summary of intercom system requirements in the areas of configuration, EMC/TEMPEST, Electrical/ Mechanical Design. These requirements form a basis for the on-going design. More detailed requirements will be developed on the basis of further study and breadboard test results. Finally, these requirements will be incorporated as part of a design specification to be delivered at the end of the contract. Subsection 2.2.2 of this report discusses classified TEMPEST material and as such is provided as a separate classified addendum.

System Configuration Requirements

During the first quarter there have been two meetings with ECOM in which system functions were discussed. These meetings resulted in a clarification of the intercom and deeper insight into intercom usage. These meetings also resulted in a refinement of the proposed system.

One area of the specification which has changed due to these meetings is the external station. The external station will not have control of the communication equipment that it will access. The control will be done at the commander's control station. In addition, discussions of auxiliary command station operation and commander station configuration took place at ECOM during the 17 November 1977 meeting. In the area of auxiliary command station operation, it was pointed out by ECOM that the main purpose for providing a second or auxiliary command station is o provide radio control by a second operator. The intent was not to connect the voice communications of two or more vehicle crews in parallel. As a result of this discussion and analysis by ITT-A/OD it was decided to provide only radio control capability for the auxiliary command station and eliminate the proposed configuration of combining voice communications. In the area of commander station configuration, an extended discussion took place as to whether the commander's headset interface and audio controls should be located as part of the commander's control station as proposed, or whether a separate station, identical to the crew member station should be provided the commander. As a result of

this discussion and analysis it was decided to stay with the proposed configuration of incorporating the commander's audio interface as part of the command station.

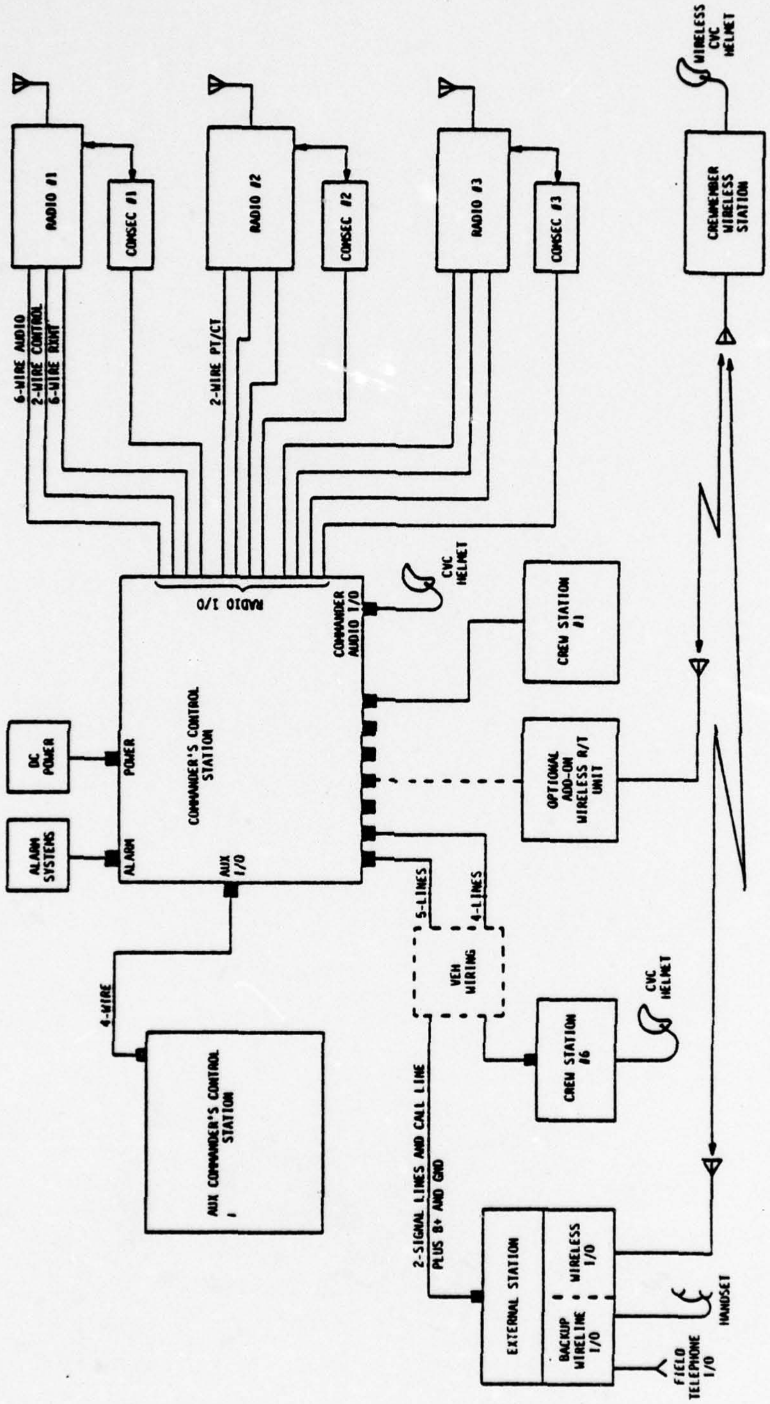
The results of the above discussions and analysis of the various subsystem requirements resulted in an intercom configuration whose operational requirements are summarized in the following subsections. The configuration requirements of the following intercom equipments are discussed:

- Commander's control station,
- Crew member station,
- External crew station,
- Command station add-on wireless R/T unit,
- Crew member wireless station

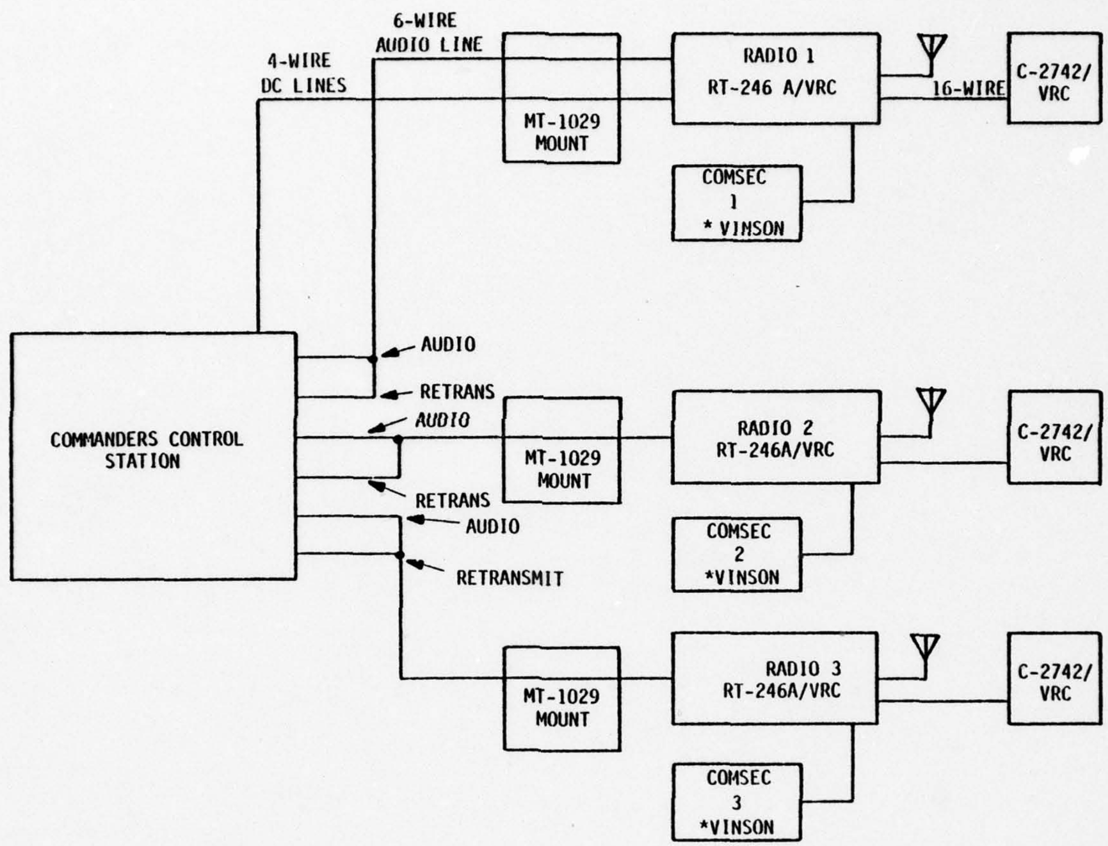
A block diagram in Figure 2-1 shows how these intercom equipments will be configured. The configuration in Figure 2-1 is shown for operation of the intercom with SINCGARS-V radios, where a 2-wire serial interface provides for transferring frequency preset, power control, and ECCM control to the SINCGARS-V radio. In addition, the intercom provides separate audio and retransmit connectors for operation with SINCGARS-V radios. This configuration is based on operation of the SINCGARS-V radio as proposed by ITT-A/OD. Final configuration is dependent on the final SINCGARS-V award. When the intercom system is used in conjunction with the AN/VRC-12 family of radios the interconnection between radios will be as shown in the block diagram, Figure 2-2.

Audio and retransmit signaling are routed through the same connector. This requires a Y cable to connect to the audio input and retransmit connectors of the intercom.

When the RT-246/VRC radios are used and remote frequency preset selection and power control are required, the C-2742/VRC is retained versus impacting the commander's control to supply this remote control signaling. The greatest impact is on the connector size which would be an 18-pin connector if the commander's module is required to select frequency presets. With the intercom controlling only the SINCGARS-V equipment only a 2-pin connector is required.



RADIO #1
RADIO #2
RADIO #3
COMSEC #1
COMSEC #2
COMSEC #3
6-WIRE AUDIO
2-WIRE CONTROL
6-WIRE RXMT
2-WIRE PT/CT
RADIO I/O
COMMANDER'S CONTROL STATION
COMMANDER AUDIO I/O
CVC HELMET
POWER
ALARM
AUX I/O
DC POWER
ALARM SYSTEMS
4-WIRE
AUX COMMANDER'S CONTROL STATION
CREW STATION #1
OPTIONAL ADD-ON WIRELESS R/T UNIT
CREWMEMBER WIRELESS STATION
WIRELESS CVC HELMET
5-LINES
4-LINES
VEH WIRING
CREW STATION #6
CVC HELMET
2-SIGNAL LINES AND CALL LINE PLUS B+ AND GND
EXTERNAL STATION
BACKUP WIRELINE I/O
WIRELESS I/O
HANDSET
FIELD TELEPHONE I/O



*WHEN SECURE MODE 6 WIRE AUDIO LINE IS CONNECTED TO COMSEC EQUIPMENT

Figure 2-2. Intercom/VRC-12 Interconnect Diagram

Commander's Control Station

The commander's control station shall provide the following operational features:

I. Radio Equipment Control

1. Power ON/OFF (3-pos.)
   a. OFF
   b. INTERCOM only (light indicator)
   c. INTERCOM & RADIOS (indicator)
2. Power level control of transmitter (6-pos.) (SINCGARS-V only)
   a. Radio has 6 output power levels which can be selected
3. Frequency preset select (6-pos.) (SINCGARS-V only)
   a. Radio has 6 presets which can be selected
4. ECCM control (2-pos.) (SINCGARS-V only)
   a. Normal
   b. ECCM
5. RETRANSMIT (2-pos.)
   a. NORMAL
   b. RETRANSMIT (radios 2 & 3 in retransmit)

II. COMSEC Equipment Control

1. Mode selection (2-pos.)
   a. Plain text
   b. Cipher text

III. Intercom Control

1. Crew member access control
   a. NORMAL (crew members have access to selection made at crew station box).
   b. INTERCOM ONLY (crew members restricted to intercom, commander has access to radios)
   c. SILENCE (only commander can communicate)
2. External Crew Station Access Control (4-position)
   a. Intercom only
   b. Intercom, R/T-1
   c. Intercom, R/T-2
   d. Intercom, R/T-3

3. External Station Monitor Control (2-position)

   a. ON, in each of the above access positions the remaining receiver units are monitored.

   b. OFF

4. External Crew Station Enable (3-position)

   a. CALL (flashes outside call light)

   b. External Enable (gives external station access to intercom and lights external access light and internal access light)

   c. OFF (locks external station out of intercom system and extinguishes internal access light and external access light).

IV. Auxiliary Command Station I/O

1. A connector and I/O network shall be provided for connecting radio command signals from an auxiliary command station. Consideration shall be given to routing the aux command station voice signal to the primary command station.

2. Power shall be routed to the aux command station via the primary command station.

3. Protocal shall be established for radio control by the two stations.

V. Crew Member Station Wireline I/O (7 I/O's)

1. A connector and I/O shall be provided for routing command/ control/ signal information between the crew stations and commander's control station.

2. Power for each crew station shall be provided to each crew station by the command station.

VI. Commander Audio I/O

1. The commander's control station shall provide connectors and I/O for attachment of the commander's audio headset. Volume control shall be provided.

2. Access control (4-positions)

   a. Intercom only

   b. Intercom, R/T-1

c. Intercom, R/T-2

d. Intercom, R/T-3

3. Monitor Control (2-position)

a. ON - in each of the above access positions the remaining radio receivers are monitored

b. OFF

4. Accent Control

a. Intercom - Intercom accented over R/T units

b. Radio - R/T units accented over intercoms

c. None - all units at same audio level

VII. Radio/COMSEC I/O

1. Connectors shall be provided for connecting up to three R/T and COMSEC equipment complements to the intercom system

a. 6-wire R/T audio

b. 6-wire R/T retransmit (SINCGARS-V only)

c. 2-wire R/T remote control (SINCGARS-V only)

d. 2-wire PT/CT COMSEC control (VINSON only)

VIII. Power I/O

1. A connector and I/O shall be provided for accepting primary dc power required for operation of the intercom and radio systems.

IX. Alarm I/O

1. A connector and I/O shall be provided for accepting vehicle alarm indicators. Provisions shall be made for routing audible alarms to all crew stations.

2.1.2 Crew Member Station

The crew member station shall provide the following operational features:

I. Access Control (4-positions)

1. Intercom only

2. Intercom, R/T-1

3. Intercom, R/T-2

4. Intercom, R/T-3

II. Monitor Control

1. ON-in each of the above access positions the remaining radio receiver units are monitored
2. OFF

III. Volume Control

IV. Audio Accessory I/O

1. A connector shall be provided for connecting audio accessories such as a CVC helmet. The I/O shall process XMIT and RCV audio signals plus radio and intercom PTT signals.

V. Remote PTT I/O

1. A connector shall be provided for connection of a remote PTT keying signal

VI. Wireless Station Battery Charge

1. A connector shall be provided for connecting a wireless intercom station to charge the batteries of the wireless crew member station.

External Crew Station

The external crew station shall provide the following operational features:

I. Controls

1. Volume
2. Access Light - indicates external station is connected in intercom system.
3. Access Request Button - flashes light at commander's control station

II. Wireless External Communications

1. The vehicle mounted external station shall provide an R/T unit to enable wireless crew member communications at distances up to 50 meters.

III. Backup Wireline Communication:

1. The vehicle mounted external station shall provide a backup wireline external communication network with an integrally mounted audio accessory (handset)

IV. Field Telephone I/O

1. Binding posts and electrical I/O shall be provided for connection of a field telephone to the external station. This I/O shall be treated as an external user by the intercom system.

Command Station Add-on Wireless R/T Unit

The command station add-on wireless R/T unit shall provide the following operational features:

I. Command Station Interface

1. The add-on wireless R/T shall be designed to interface with the commander's control station via the 2-wire TDM link. Local access controls and remotely received wireless signals shall be transferred to the commander's control station via the TDM wireline link.

II. Controls

1. Access control
   a. Intercom only
   b. Intercom, R/T-1
   c. Intercom, R/T-2
   d. Intercom, R/T-3
2. Monitor Control
   a. ON - in each of the above access positions the remaining receiver units are monitored.
   b. OFF
3. DC Control
   a. ON
   b. OFF

III. Wireless Interface

1. The add-on wireless R/T unit shall provide for transmission to and reception from crew members equipped with wireless station equipment. The add-on wireless station shall be capable of being mounted anywhere in the vehicle such that wireless coverage is provided to all users.

Wireless Crew Station

The wireless crew member station shall provide the following operational features:

I. Controls

1. Access Control

   a. Internal Vehicle Operation - In this mode radio and intercom access is determined by switches located at the commander's control station add-on wireless R/T unit.

   b. External Vehicle Operation - In this mode radio and intercom access is determined by external station control switches located at the commander's control station.

2. PTT

   a. PTT control shall be generated by CVC helmet switches or VOX techniques shall be implemented if feasible to provide hands-free PTT operation

3. Volume

II. Interface

1. Audio Accessory - The wireless station shall interface with standard audio accessories such as a CVC helmet

2. Battery Charger - A connector shall be provided for charging wireless unit batteries.

EMC/TEMPEST Requirements

EMC Requirements per MIL-STD-461

The intercom system will be designed to operate and be compatible with the electronic equipment within army armored vehicles and as such will be designed to meet the requirements of MIL-STD-461 (Electromagnetic Interference Characteristics, Requirements for Equipment Subsystems and Systems). The requirements of MIL-STD-461 were assessed with respect to the intercom system and the following test categories were determined to be applicable:

CE01 - Electromagnetic emissions on dc power lines infrequency range of 30 Hz to 50 kHz

CE04 - Electromagnetic emissions on power lines in frequency range of 10 kHz to 50 MHz

CE03 - CE05 - Electromagnetic emissions on control leads, signal leads and interconnecting cables in the frequency range of 30 Hz to 50 MHz.

CS01 - Electromagnetic interference injected on dc power lines in frequency range of 30 Hz to 50 kHz

CS02 - Electromagnetic interference injected on power lines in frequency range of 50 kHz to 400 MHz

CS06 - Electric spike interference on dc power line

RE02 - Narrowband and broadband E-field emissions in the frequency range of 14 kHz to 10 GHz.

RS02 - E-field interference due to electric spikes

RS03 - Radiated interference in the frequence range of 10 kHz to 12 GHz.

In addition to meeting the requirements of MIL-STD-461 for the above test categories, the intercom system must also operate in the electromagnetic environment of current Army armored vehicles. The electromagnetic profile of armored vehicles was defined by ECOM during discussions on 17 November 1977. The data presented by ECOM is shown in Figure 2-3. On the basis of data in this figure, it is clear that the intercom system design must take into account the existence of vehicular electronic equipment in implementing intercom wireless communication and TDM signal distribution techniques. For this reason, figure 2.2-1 will be used as a design guide in the development and design of the intercom system. Specifically, if time division multiplexing techniques are utilized in distributing intercom signals, then electromagnetic energy radiated by high speed, short-duration TDM pulses must be limited within MIL-STD-461 levels and analysis should be made to assure the passing of such signals through tank slip rings does not present an EMI problem with respec tto other circuits. If wireless techniques are implemented, then the spectral occupancy of these signals should fall outside the occupied bandwidth of the VRC-12 and VRC-24 radios. In addition, the

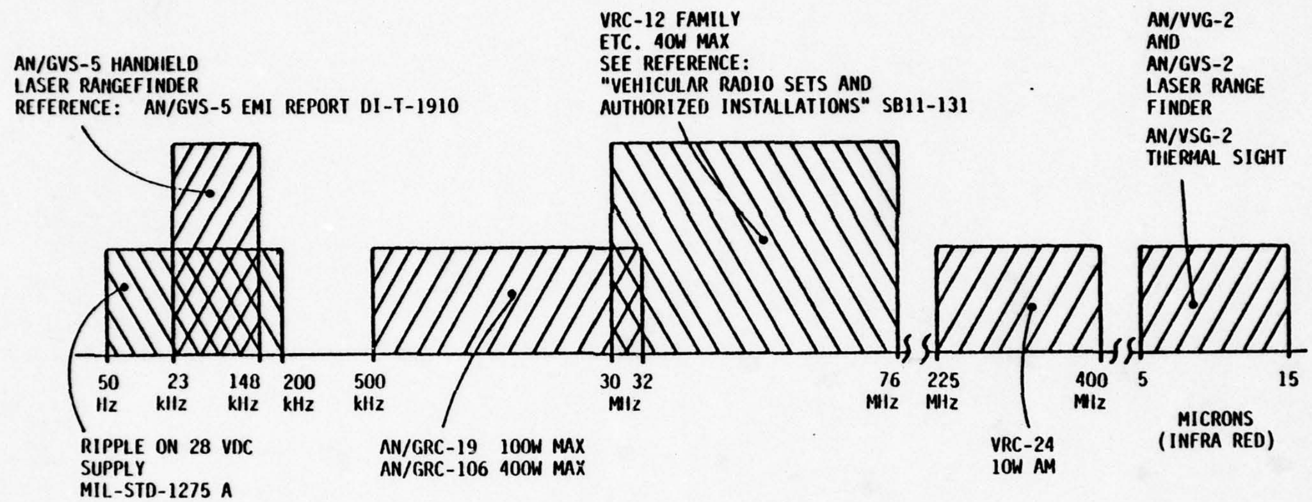


Figure 2-3. Ground Combat Vehicle EM Profile

wireless techniques should consider that existence of harmonic and spurious interference generated by these radios might disable wireless intercom operation.

TEMPEST Requirements

The discussion of TEMPEST requirements is presented in classified Appendix B to this report.

Electrical/Mechanical Design Requirements

Electrical Requirements

The following electrical design requirements were developed for the intercom system:

1. Built-in-Test Equipment (BITE) - The commander's control station shall be capable of testing and verifying the operation of each communication link between the commander's control station and the user's station, including the external station. The commander's control station should also provide for self-test of vehicle warning signals. To reduce front panel clutter BITE functions should be located apart from the front panel.
2. Nuclear Survivability - The nuclear survivability requirements for the intercom system are set forth in DS-AF-0247A(A). To meet these requirements during this study contract key aspects of a nuclear survivability program will be defined. This will be a balanced program which will assure that no one circuit is especially vulnerable versus the remaining radio circuits. As a minimum the nuclear survivability program should recommend hardening methodologies, validation procedures and quality assurance. This nuclear survivability program shall be delivered as part of the final study report and shall reflect the intercom system design as developed at that time. In addition to meeting the requirements of DS-AF-0247A(A), consideration will also be given to the effects electromagnetic pulses generated by nuclear detonations. In particular, EMP protection shall be provided on all critical lines, such as those power and signal lines feeding the external station. All interconnecting cables shall be shielded and grounded to provide a measure of protection against EMP.
3. Electromagnetic Interference (EMI) Noise Cancellation - To the maximum extent feasible, every effort shall be made to reduce the effects of EMI interference in the intercom system. Section 2.1.3 of the proposal addressed in detail design approaches which must be used to eliminate EMI. As the detailed design of the intercom system progresses, the Interference Reduction Guide for Design Engineers (Vols.I and II) shall be used as a guideline in implementing EMI design techniques.

4. Voice Channel Bandwidth - The voice channel bandwidth in a vehicular communications system is critical to the voice intelligibility of the system. Due to the existence of low frequency background noise at levls up to 110 dB (SPL), it is desirable to take advantage of the high frequency voice components to maintain and improve voice intelligibility in this high noise environment. In accordance with paragraph 3.9 of DS-AF-0246A(A) an audio bandwidth of 300 Hz to 6 kHz shall be maintained within the intercom system. The audio bandpass characteristic should provide a very sharp cut-off at frequencies below 300 Hz to minimize interference due to low frequency background noise. A combination of sharp low frequency cut-off, microphone noise cancellation and headphone earmuff noise rejection will contribute significantly to improved intercom voice intelligibility performance. To the maximum extent feasible, the effects of a sharp, high-pass cut-off at 300 Hz in the voiceband on improving noise rejection will be investigated.
5. Voice Intelligibility - Voice intelligibility criteria shall be established to measure the performance of the intercom system in a high noise environment. These criteria shall be incorporated in the final study report. Test methods such as modified rhyme tests, phonetically balanced word lists, etc. shall be specified. During the study effort design techniques for processing the voice signal shall be developed which will meet these criteria. Analysis shall be performed to verify the ability of the proposed intercom system to meet voice intelligibility criteria in a given background noise environment. This analysis will, to the maximum extent feasible, include the effects of microphone noise cancellation, headphone earmuff noise rejection, intercom audio bandwidth, intercom quantization noise levels, background noise levels and output signal linearity. The results of this analysis shall be included in the final study report.
6. Audio Output Level - The intercom shall provide up to 200 mw of audio power to the user headset at each station (external, user, commander and wireless). At a peak output power level of 200 mw, the output amplifier shall be linear to within 7%. It is recommended

that the combination of 1 mw output power at 600 ohms results in a sound pressure level of +105 dBA* at each headphone earpiece and that the headphone provide a linear sound level output up to input power levels of 200 mw. This will result in a sound pressure level of +128 dBA to the user. It is important to note that at this sound pressure level of +128 dBA, permanent damage to user's hearing could result. Safety provisions shall be devised to prevent constant exposure of the user to this sound level and these provisions shall be developed in detail in the final study report.

7. Wireless Station - The wireless intercom stations shall be designed to operate from re-chargeable batteries and the battery material used shall be evaluated in terms of safety, when battle damage results in contact of battery materials with the user's body. The wireless station communication technique shall also meet radiation safety levels of less than 10 mw/cm^2 for RF signals from 10 MHz to 300 GHz. The wireless communication technique shall provide continuous operation inside and outside the vehicle and shall operate at ranges up to 50 meters from the vehicle.
8. Station Control - A centralized control approach shall be developed to provide for both radio and intercom system control from the commander's control station.
9. Electrical Design - Modern electrical integrated circuits shall be utilized to the maximum extent feasible to reduce equipment size, reduce power consumption, increase reliability and lower cost.
10. Signal Multiplexing - Signal multiplexing techniques will be employed to reduce the number of station interconnecting lines and size of signal connectors. Selected multiplexing techniques shall to the maximum extent feasible provide a high degree of noise immunity, crosstalk rejection and shall not require a large complement of electrical circuitry.

Mechanical Specification

Mechanical specifications for the vehicular intercommunication system will be centered around four areas. These are human factors,

* 0 dBA = 2×10^{-4} $dynes/cm^2$

environmental conditions, physical size and shape, and materials and material finishes.

A prime consideration in the success of the intercom system is the man-machine interface. The radio control panel lay-out should be designed in a manner such that operation is self-explanatory. The user should be able to control the equipment with a minimum of thought or switches to turn or observe. Devices like hands-free keying or a separate keying device optimumly located would provide the user with minimum movement in radio operation. Another important consideration is the systems installation and maintainability. Connections to the intercom will be easy to use and keyed in such a manner that incorrect connection would be impossible.

Environmentally, there are two areas which require careful attention to specifications: the external unit and vibration requirement in general. The external station must be designed in such a manner to withstand all natural elements and those forces imposed on it by the tank. (i.e. mussle blast of the cannon, operator abuse, weapons fire) the severe nature of the vibration and shock encountered makes the durability of the whole system an important consideration.

The basic size and form factors of the equipment are also of key importance to the intercom success. The system size will be the same size or smaller than previous units and with a form factor that makes it as safe as possible for the user.

The material used in construction will basically be cast aluminum. Other materials will be chosen with standards that already exist in MIL-STD-5400. Finishes of the intercom will be able to take the abuse a system of this type will receive.

3.0 Evaluation and Development of Technical Approaches

Wireless Communication Techniques

A preliminary analysis was made on the use of infra-red, microwave, and R.F./FM for wireless operation. The analysis considered the operational environment both internal and external to the tracked vehicle and the transmission path. Based on the analysis infra-red and microwave areas of the frequency spectrum were tentatively eliminated as viable candidates for wireless operation. Radio frequencies just above 400 MHz with FM modulation show promise as a good candidate for wireless operation.

The implementation of wireless communication techniques for the intercom system involves two design areas:

1. Transmission Technique - This design area requires the selection of the appropriate transmission medium (acoustic, I.R., RF) for use in the vehicular intercom system. Parameters which affect selection include: noise interference, safety, power consumption, etc.
2. Modulation Technique - This design area requires the selection of an appropriate modulation method which can convey the necessary voice information in a manner compatible with the overall operation of the intercom system. Modulation methods must consider requirements for multiple channel operation, transmission of control information and simplicity of modulator/demodulator circuit designs.

Several combinations of modulation techniques and transmission medium are possible in implementing wireless intercom communications. Those combinations considered most viable are listed as follows with their significant operational features:

1. Acoustic/AM - In this technique, voice information is AM modulated onto an acoustic carrier in the frequency range of 40 kHz to 400 kHz. Acoustic transducers are used to transmit and receive the signal. Multiple channel wireless operation requires the use of multiple frequencies in an FDM format.
2. Infra-Red/FM - In this technique voice information is used to FM modulate a 100 kHz pulse train, which then pulse modulates a I.R. emitting diode. The I.R. pulses are detected at the receiver and

FM demodulated. This modulation method can only provide single channel operation.

3. Infra-Red/TDM - In this technique several voice channels are formatted as a TDM signal and the pulses are modulated onto an IR carrier. The I.R. pulses are detected at the receiver and de-multiplexed. This method provides for multiple channel wireless operation.
4. Microwave/FM - This technique is similar to IR/FM except a microwave carrier at about 8 GHz is used instead of I.R.
5. Microwave/TDM - This technique is similar to IR/TDM except a microwave carrier at about 8 GHZ is used instead of IR.
6. RF/FM - In this technique voice information is FM modulated onto a carrier in the VHF or UHF frequency range. A conventional heterodyne receiver and FM discriminator provides for demodulation of the voice signal. Multiple channel wireless operation requires the use of multiple frequencies in an FDM format.

In the ITT-A/OD proposal a microwave TDM wireless approach was considered most viable and was recommended for implementation. It was stated in the proposal that all approaches would be re-evaluated during the study program in terms of original system requirements and any new system requirements. Factors not considered in the proposal which now affect design of the wireless intercom technique are listed as follows:

1. External wireless operation by vehicle crew members at distances up to 50 meters from the vehicle is highly desirable. Wireless operation would eliminate a very cumbersome 50 meter wireline external station.
2. TEMPEST limits restrict the radiation of wireless communication signals beyond a perimeter specified in Section 2 of this report.
3. Operation on independent wireless channels by each wireless user is not considered an overriding design requirement.

Operation external to the vehicle presents several problems for the IR and microwave systems previously proposed. When only operation inside the vehicle was considered, path loss and respective transmit power was small, interference due to light was negligible, variation in signal level was minimal. Outside the vehicle these variables

are no longer well controlled. Consideration was given to providing wireless microwave or I.R. communication inside the vehicle and wireless VHF/UHF communication outside the vehicle. This was rejected since this would require the costly development of two wireless communication techniques and would also require the crew members to change wireless apparatus as they move from inside to outside the vehicle. For this reason it was decided to pursue the development of a wireless technique which would provide operation both internal and external to the vehicle. Prior to proceeding with a discussion of possible approaches, a brief summary of attributes which make the use of Microwave/TDM and IR/TDM undesirable is presented:

1. <u>Receiver Sensitivity</u> - At short ranges inside a vehicle the receiver sensitivity of IR detectors and microwave detectors required the transmission of low power level for the given path loss. In an external environment at ranges up to 50 meters the required transmit signal power for both IR and microwave is very high due to increased path loss and low detector sensitivity. In the microwave case, tangential diode detectors could be replaced by more sensitive heterodyne receivers but this would be quite expensive.
2. <u>Pulse Detection and AGC</u> - At short ranges inside the vehicle the received pulse strength of pulses being received from multiple users do not vary greatly in level when a TDM signal format is being used. When this same signal format is used outside the vehicle, the received pulse strength from multiple users will vary greatly in level. This presents a level detection and AGC design problem which is quite difficult to solve. Fast acting AGC networks are potentially unstable and adaptive pulse detection networks are expensive.
3. <u>Detectability</u> - The operation of an I.R. wireless system outside the vehicle poses a severe detectability problem in that I.R. tracking by enemy weapons is quite easy. The use of microwave wireless also poses a TEMPEST problem. The use of low sensitivity tangential detectors in the receiver requires the reception of high signal powers (>-55 dBm) at a range of 50 meters. Path attenuation of

this signal at ranges much greater than 50 meters is not great enough to preclude detection by the enemy.

4. Interference - The operation of an I.R. wireless system outside the vehicle in daylight is precluded by interference due to sunlight.

For the above operational problems an analysis is presented in the attached appendices concerning microwave transmission at 50 meters and I.R. operation in the presence of light interference.

Given the fact that microwave and I.R. wireless techniques are no longer suitable for application to the intercom system for both internal and external vehicle operation, it was necessary to analyze alternate wireless communication methods. Two wireless techniques were considered: Acoustic and VHF or UHF RF signaling. For each of these approaches single channel operation was considered most viable. Acoustic methods do not have the bandwidth to support TDM modulation formats and multiple channel FDM signaling requires multiple transmitter/receiver units. AM modulation of a single acoustic carrier was therefore considered the most viable approach. For VHF or UHF wireless operation, it is necessary to select a carrier frequency which will operate on a non-interference basis with electronic equipment in the vehicle. On the basis of electromagnetic compatibility data presented on 17 November 1977 by ECOM and shown in figure 2-3 of Section 2, it was decided that operation just above 400 MHz was most desirable. Operation at this frequency requires small antennas and can utilize efficient solid state circuit designs.

Several modulation methods were considered for operation with the UHF wireless R/T unit. These included: TDM pulse modulation (multiple channels), AM, FM, FDM (multiple channels). A trade-off analysis of possible modulation techniques is presented in Table 3-I.

Serious consideration was given to multiple channel TDM and FDM modulation techniques. As mentioned before, TDM has the inherent problem that the central receiver must accept RF pulses of greatly varying signal levels from the independent wireless users. This condition makes reliable detection of these pulses quite difficult and for this reason TDM modulation is not considered at this time. FDM wireless

Table 3-I. Wireless UHF Modulation Techniques

	MODULATION TECHNIQUE			
Criteria	AM	FM	TDM	FDM
1. Channel capacity	Single channel AM	Single channel FM	Multiple Independent channels	Multiple independent channels
2. B.W. Occupancy	R.F. B.W. = ± 6 kHz	R.F. B.W. = $2(\Delta F + F_m)$ $F_m = 6$ kHz $\Delta F \approx 60$ kHz	R.F. B.W. ~ 1 MHz	R.F. B.W. = Ch. B.W. x No. of channels
3. Relative Receiver Sensitivity	Good	Good	Poor	Good
4. Circuit Design Complexity	1. AM modulation loop 2. Heterodyne receiver with AGC 3. Xtal controlled exciters & L.O.	1. FM VCO modulator 2. Heterodyne receiver with limiter/disc 3. Xtal controlled exciter & L.O.	1. On/OFF keying 2. Heterodyne receiver with AGC. Central receiver must detect multiple signal levels from independent users. 3. Xtal controlled exciter & L.O.	1. AM or FM modulation 2. Heterodyne receiver. Central receiver must provide multiple I.F. Sections for each channel. 3. Multiple XTAL or synthesizer provides for multiple channel operation.

modulation was also considered using either AM or FM channel modulation. The principal drawbacks to FDM modulations are the requirements for multiple I.F. sections and detectors at the central receiver and the requirement for multiple crystals or synthesizer to provide channel selection. The circuit complexity of FDM therefore ruled out its use as a wireless techniques.

For single channel UHF wireless operation both analog AM and FM modulation were considered. Both techniques provide about equivalent performance in terms of receiver sensitivity requirements. The FM approach was chosen over AM for the following reasons:

1. FM modulation provides immunity against EMI
2. Class C output amplifiers are easier to implement than respective Class A AM output amplifiers.
3. FM modulation provides increased post detection SNR ratios than AM and results in better voice quality.

On the basis of these trade-offs the transmission and reception characteristics of a single channel UHF/FM wireless link were analyzed in detail. This analysis is presented in detail in Appendix B of this report. In addition, Appendix B includes analysis of I.R. and microwave wirless communication links. The results of these analyses are summarized in Table 3-II. Included in Table 3-II are the characteristics for an acoustic wireless link. Data on acoustic wireless operation is being compiled at this time. Results of analysis of an acoustic wireless link will be reported in the next quarter.

The results presented in Table 3-II and the analysis of Appendix B show that the use of either microwave or I.R. wireless communication techniques outside the vehicle are virtually impossible. This is due to the high path loss of bothI.R. and microwave and the fact that omni-directional coverage must be provided. In general,directional microwave and I.R. links have been deployed which provide long range communications at transmit power levels much less than those listed and at ranges much greater than 50 meters. These links, however, employ high gain antennas or directional lens and usually employ sensitive heterodyne receivers. None of these design techniques are applicable

Table 3-II. Summary of Wirelss Communication Techniques Considered to date:

Characteristics	UHF-FM Wireless Link	Pulse Modulated I.R. Link (wave length = .9μm)	Pulse Modulated Microwave Link (Fc=7.5GHz)	Acoustic Link
1. Modulation method	FM modulation via voltage controlled oscillator carrier freq. = 415 MHz	Pulsed ON/OFF modulation of IR emitting diode array (wave length ≈ 0.9 μm). Pulses may be FM modulated for single channel mode.	Pulsed ON/OFF modulation of Gunn diode or GaAs FET oscillator. Pulses may be FM modulated for single channel operation.	AM modulation of acoustic carrier frequency which drives output ceramic transducer.
2. Demodulator	Heterodyne receiver plus limiting IF & FM discriminator	IR diode detector, video amp with AGC, data pulse level detector and frequency to voltage converter	Schottky diode detector, video amp with AGC, data pulse level detector and frequency to voltage converter.	Ceramic transducer receiver, I.F. amp with AGC, AM detector.
3. Bandwidth Requirement	R.F. B.W. = 2 (ΔF+ Fm) $\Delta F = \pm 60$ kHz Fm= ± 6 kHz	R.F. B.W. $\approx \frac{1}{\text{Pulsewidth}}$	R.F. B.W. $\frac{1}{\text{Pulsewidth}}$	Acoustic B.W.= ± 6kHz
4. Receiver Sensitivity	Pre-detection SNR >10 dB Received signal power = -103 dBm RCV N.F.= 8 dB Post detection SNR = 40 dB	Post detection SNR > 10 dB Received light power = 2×10^{-9} watts/mm^2 Detected noise is function of background light interference	Post detection SNR > 10 dB. Diode sensitivity =10 dB output SNR for -59 dBm input (B.W.=2 MHz) Received power ≈ 60 dBm	Receiver sensitivity = -50 dB volt/μbar Post detection SNR 10 dB. Detected noise is function of background acoustic interference. Received power +50 dB (SPL)

Table 3-II. (Cont)

Characteristics	UHF-FM Wireless Link	Pulse Modulated I.R. Link (Wave length-.9μm)	Pulse Modulated Microwave Link Fc=7.5GHz)	Acoustic Link
5. Path loss at 50 meters	Path loss=59 dB Antenna gain=7dB (XMIT & RCV)	Loss $\frac{1}{R^2}$	Loss $\frac{1}{R^2}$	0.4 dB/ft at 33 kHz 1 dB/ft at 100 kHz
6. XMIT Power	-52 dBm	5 watts/steradian (impractical XMIT power level)	.25 watts(impractical XMIT power level)	+110 dB(SPL) @33kHz
7. Detectability	At perimeter specified in section 2.2 of this report, radiation level is within TEMPEST requirements.	High intensity I.R. system easily detected by enemy I.R. tracking weapons	High level omnidirectional microwave signal easily detected by enemy directional antennas	Acoustic wireless techniques are virtually undetectable by the enemy at ranges in excess of boom.
8. DC power consumption	low due to low XMIT power requirements and efficient Xmitter	Diode emitter efficiency results in high power consumption.	Microwave transmitter power efficiency is low and results in high power consumption	Acoustic transducers result in fairly efficient use of DC power.

to the vehicular intercom wireless station. For these reasons both microwave and I.R. wireless communication is eliminated from further consideration. Of the two remaining wireless approaches under consideration, UHF-FM is at present being considered the most feasible approach. Acoustic wireless communication has several excellent operating characteristics which were listed in the proposal; however, the existence of high background noise in both external and internal operation presents a problem. Also, operation of an acoustic wireless system internal to armored vehicles presents a severe interference due to vehicle vibration. Further detailed analysis of an acoustic wireless approach will be performed in the next reporting period.

The use of UHF-FM wireless communication solves many of the operational problems associated with wireless communications for army vehicular intercoms. The salient features of UHF-FM wireless communication are listed as follows, while a detailed analysis of UHF-FM RF link performance is presented in Appendix B.

1. UHF-FM at 415 MHz utilizes small antennas which are easily packaged in a man-transportable package. These antennas provide omni-directional coverage and do not require the location of several arrays around the vehicle.
2. UHF-FM employs wideband FM modulation techniques which provide excellent voice intelligibility and provides rejection of static electrical noise interference.
3. UHF-FM can be constructed with simple solid state and LSI integrated circuits such that the wireless unit can be packaged in a very small volume.
4. UHF-FM can be operated at very low transmit power levels due to the use of sensitive heterodyne receiving techniques. This minimizes d-c power consumption and assures radiated power levels beyond a given range perimeter are not detected by the enemy.

3.2 Multiplexing Techniques

In determining a multiplexing technique to be used in the Vehicular Intercom System it is important to first consider the distribution system to be used as it limits the multiplexing techniques which can be used effectively. The two distribution systems that have been

considered are Bus distribution and Star distribution. In a Bus distribution system there is one main bus carrying information for all of the substations. This requires multiplexing of information for use by the substations. In a Star distribution system, each substation has its own bus. The Bus distribution method has the advantage of reducing interconnecting wires to a minimum but it has the disadvantage that a single bus failure due to combat damage or ordinary electrical failure can disable the whole intercom system. The reliability of a bus system can be increased by operating parallel busses. A Star distribution system increases overall intercom reliability, since combat damage to one station does not affect the entire system. Individual signal distribution requires an increased number of cables and connectors. This can be reduced by multiplexing control information onto the voice channel either in terms of tones or a Time Division Multiplexing (TDM). A Star distribution system lowers the operating frequency of the interconnect lines. This is particularly important due to the anticipated problems of noise susceptibility when passing through the tank slip rings. In summary of distribution techniques, the Star system is chosen over the Bus system because of increased reliability and lower operating frequency.

The use of multiplexing techniques reduces considerably the number of interconnecting wires between the commander's control station and the user's substation. This reduces the cost of connectors and cables. The reduction of cable-wire count is also very important for tank installations where the number of turret slip rings is limited. The three multiplexing techniques to be considered are Time Division Multiplexing (TDM), Frequency Division Multiplexing (FDM) and Space Division Multiplexing. In a TDM system, voice signals are sampled and encoded in an asynchronous serial bit stream. Voice signals are then assigned specific time slots for transmission on a single wire to the user. Command information is easily interleaved with the digital voice for transmission on the same line. In a FDM system, command information must be encoded as multifrequency tones for transmission on individual

voice channels. Filters must be designed to decode this information. In Space Division Multiplexing, separate wire lines are used to route the required voice and control information to each user.

The advantage of TDM over FDM is the suppression of the high background noise characteristic of current analog systems since information is carried in the absolute levels of the data bit (additive noise is removed when the decision is made between logic "0" and "1"). A TDM system uses all digital signal processing which requires no special alighment or tuning. Digital circuit designs exhibit increased reliability over analog circuits and can be easily packaged as custom LSI networks to decrease system size and cost. A TDM system lends itself very well to the use of fiber optics.

The advantage of Space Division Multiplexing is that it requires very simple electrical circuits to provide for the distribution of the various signals. Its main disadvantage is that a large number of wirelines is required to transmit the required information and this results in bulky cables and large expensive connectors. A compromise can often be made in designing wireline communication networks by combining the salient attributes of TDM and Space Division Multiplexing. In the intercom system, separate wirelines could be employed by voice and control information. Control bits would be multiplexed on a separate unbalanced wireline at a very low bit rate. High speed digital voice signals would be multiplexed on separate balanced wirelines. The advantages and disadvantages of the above multiplexing techniques are summarized in Table 3-III.

On the basis of the results in Table 3-III, FDM multiplexing is not considered viable since it provides no measure of noise rejection so critical to the intercom system and also because the high degree of circuit complexity is costly. The Space Division Multiplexing approach is also rejected since it requires a large number of wirelines which results in bulky cables and expensive large connectors. The large connectors are also not practical, given the fact that seven crew member stations must be connected and a small intercom form factor is required (i.e. panel space for connectors is limited). This leaves TDM and a hybrid TDM approach as the most viable candidates. The

Table 3-III. Multiplexing Technique Trade-Off

	Multiplexing Technique			
Criteria	FDM	TDM	Space Division Multiplexing	Hybrid TDM Plus Space Division
Noise Immunity	1.Analog FDM Signal Distribution techniques are susceptible additive noise.	1.Digital TDM signal distribution techniques provide a measure of additive noise rejection	1.If separate wireline distribution is used digital voice encoding should be used in preference to analog voice to provide noise rejection.	1.Digital voice encoding provides noise rejection.
Circuit Complexity	1.Relatively complex frequency tuning network required to provide channel selection.Analog tone generator/detectors required to transmit control information.	2.Relatively simple digital timing networks required to provide channel selection. Digital CVSD encoders available as off-the-shelf LSI circuits	2.No channel selection circuitry required.Simple switching provides selection of appropriate channel.	2.Channel selection circuitry minimized. Off-the-shelf UART's can be used to process serial TDM control data.
Wiring	3.Multiple wireline cables reduced. Connector size reduced.	3.Multiple wireline cables reduced.Connector size reduced.	3.Several wirelines required and large cable connectors.	3.Relatively few wirelines and smaller connectors than space division approach.

following paragraphs present a description of a fairly simple TDM approach which is under consideration. In the next reporting period, consideration will be given to implementing a hybrid TDM/Space Division approach which will simplify circuitry while not requiring a severe increase in wirelines.

In designing a TDM system, a major emphasis should be placed on specifying a format for transmission of digital information between the commander's control station and the user's substation. Formatting affects the operating frequency of the transmission line and consequently the areas of: compromising emanation, noise susceptibilty, generation of noise affecting other vehicular systems and power consumption. Other areas affected by formatting include error rates and control bit synchronization. In summary,the three objectives are:

- Lowest possible bit rate,
- low error rate,
- ability to re-acquire synchronization without a noticeable degradation of system performance.

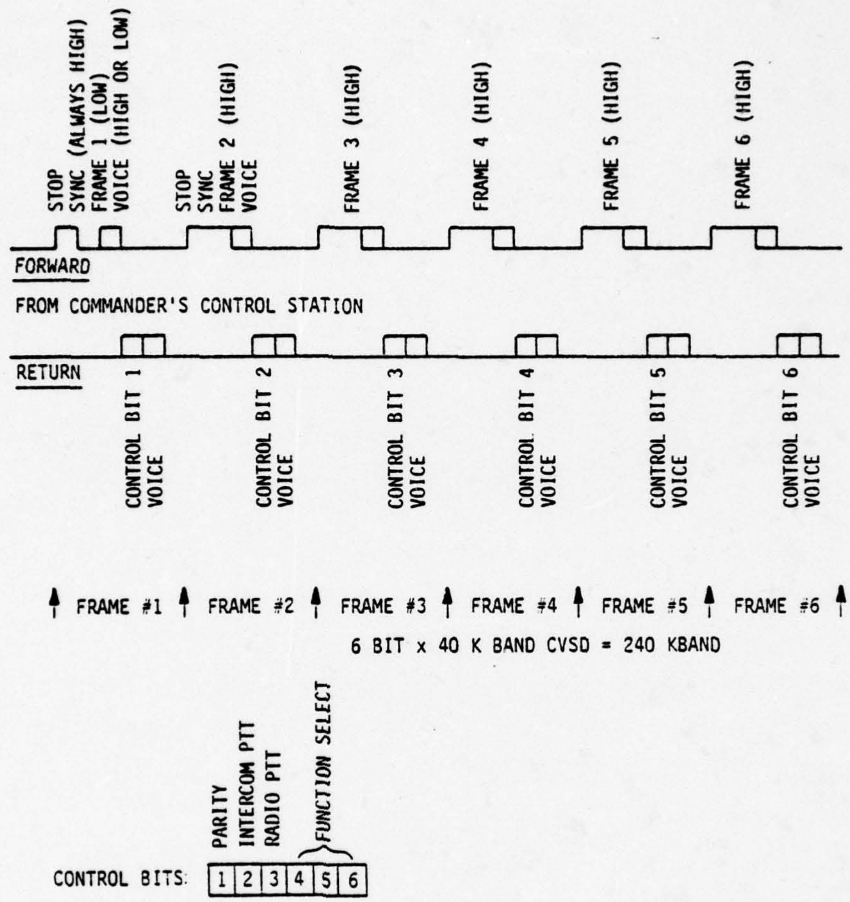
Referring to figure 2.3.5-2 of proposal, a TDM approach was presented that provides for multiple wireless user channels. Our analysis has shown that only one wireless channel is needed. Restricting the system to one wireless channel will lower the bit rate to 640 Kbaud. This is an extremely high bit rate and may impose noise susceptibility problems in transmission through the tank turret slip rings. Further reduction in the bit rate to 240 Kbaud can be accomplished by decreasing the number of foward bits being transmitted. Since a Star distirbution technique is being used in transmission of data it is possible to send to each substation, individually, the required bit of voice as opposed to sending all 5 bits of voice information and deselecting the bits at the substation. This results in a slight increase in hardware at the commander's control station but is offset by a decrease in substation hardware and simplicity in designing low frequency drivers and digital circuitry. Further decrease of system operating frequency can be accomplished by simplifications of synchronization

bits allowed by decrease in voice bits transmitted. Figure 3-2 illustrates this. The format is similar to that of a universal asynchronous receiver transmitter. Synchronization is accomplished by detecting the positive transition of the synchronous bit. Data is detected by sampling the line at fixed intervals in relation to the synchronization bit. A stop bit is added to verify proper timing and framing. The stop bit guarantees a transition when the synchronization bit is transmitted.

Figure 3-3 gives the Voice Signal Interconnect Diagram for TDM Signal Distribution. Shown therein are the transmit and receive audio modules, reference clock and TDM timing control module, one of the seven TDM interface networks, and one of the seven user stations. Not shown for simplicity are the wireless and commander stations and the alarm interface. CVSD is used per proposal recommendation in a TDM Star Distribution system. The block diagram shows the preliminary breakdown of the intercom system into separate printed circuit boards. The transmit and receive audio was placed on separate cards to provide for electrical isolation. Reference clock and TDM timing control card provides common timing and control signals for the seven TDM interface network cards and the CVSD chips on the transmit and receive audio cards. The seven TDM interface cards are identical and may be interchanged. User stations are in the same way identical and may be interchanged. (i.e. require no modifications or programming as to its location in the intercom system). The external station, however, will have some differences in that the controls will not be utilized. Details will be developed in the next quarter.

Control Techniques

The vehicular intercom system will be required to process a large amount of control information versus the AN/VIC-1. This is due to the fact that control of the vehicular radios and intercom stations is centralized at the commander's control station. Intercom/Radio functions which must be controlled are described as follows:



FUNCTION SELECT:

BIT 4	BIT 5	BIT 6	SWITCH POSITION	XMIT	RCV
0	0	0	INTERCOM ONLY		
0	0	1	INTERCOM + RADIO	1	1
0	1	0	INTERCOM + RADIO	2	2
0	1	1	INTERCOM + RADIO	3	3
1	0	1	INTERCOM + RADIO	1	1,2,3
1	1	0	INTERCOM + RADIO	2	1,2,3
1	1	1	INTERCOM + RADIO	3	1,2,3

Figure 3-1. TDM Format

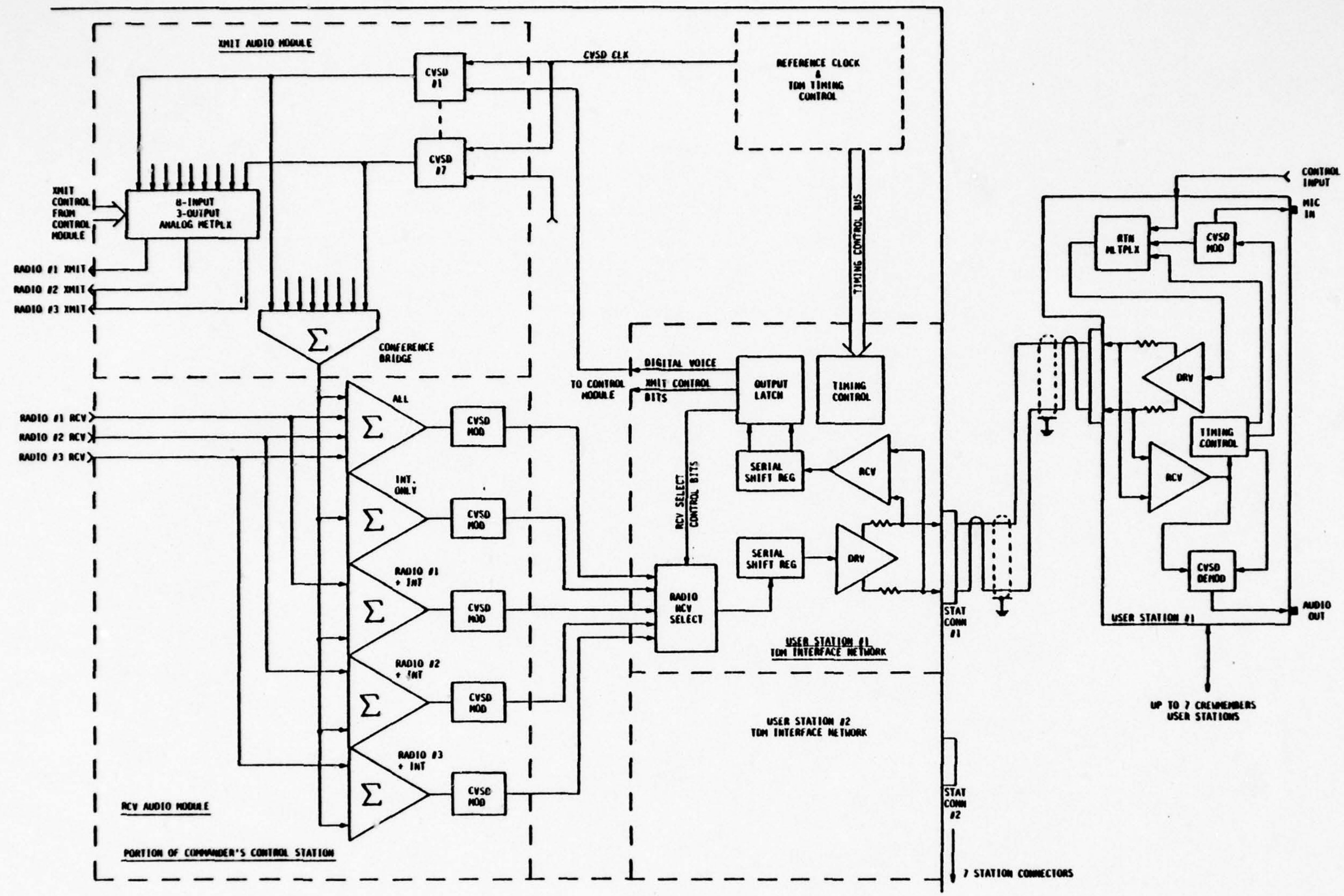


Figure 3-2. Voice Signal Interconnect Diagram for TDM Signal Distribution

1. Radio Controls - Front panel switches are provided on the intercom commander's control station for operating up to three vehicular R/T units. Controls include: frequency presets, RF power select, ECCM, PT/CT. In SINCGARS-V radio installations these controls must be formatted serially for transfer to the SINCGARS-V radio.
2. Crewmember Station Control - The operation of crew member stations must be monitored and to some degree controlled by the commander's control station. Functions to be controlled include: Radio access, external station intercom/radio access and alarm distribution.
3. Auxiliary Command Station - Provisions must be made for connection of an auxiliary command station to the commander's station such that a second crew member can have access to control of the vehicular radios by the primary and auxiliary command station.

A block diagram is shown in Figure 3-3, which illustrates the present assessment of control functions which must be processed by the intercom commander's control station. In this diagram it is seen that control busses distribute and collect control information from four areas: crew member stations, vehicular radios, commander control station front panel and XMIT audio module. The processing of this information is provided by the controller I/O and central controller unit of Figure 3-3. The electrical design of these control networks must provide an efficient I/O which minimizes interconnect wires and control circuits which minimize hardware. Two approaches to the design of these I/O and control circuits have been studied and these are:

1. Discrete I/O under control of a dedicated discrete logic network.
2. Discrete I/O which can be combined into an integrated control subsystem under microprocessor control.

In Figure 3-3, it is necessary for the controller I/O to provide the following interface functions:

1. Front Panel Controls - 15 lines of discrete control information must be processed and routed to respective radio and intercom control outputs.

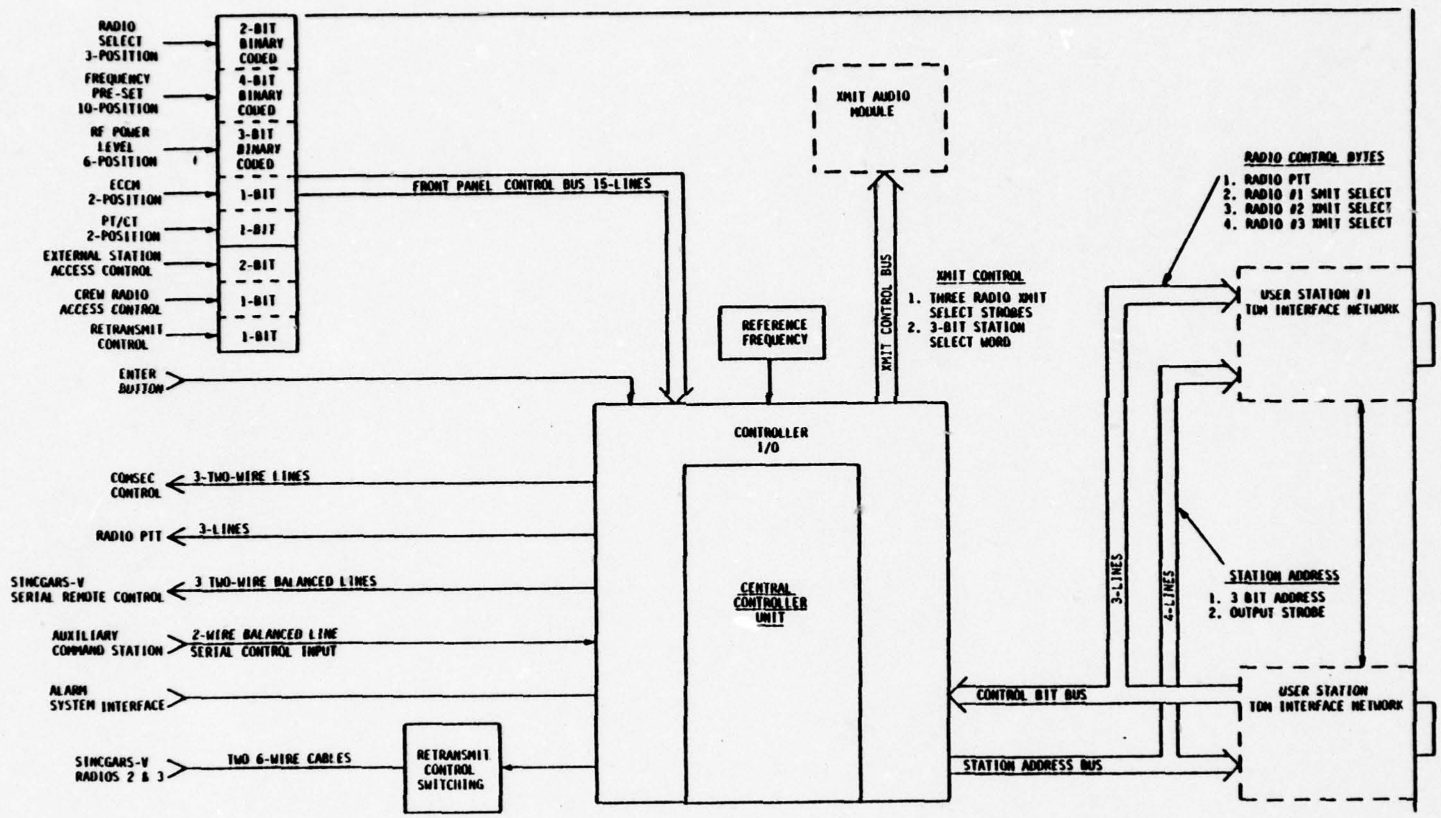


Figure 3-3. Control Signal Interface Diagram

2. Crew Member Station Radio Control - Radio control bytes from the crew member stations are received via the TDM interface. These control bytes must be processed and then routed to the XMIT Audio Module which selects the appropriate radio for transmission. Also the PTT control bit is routed to the respective radio depending on the position of the command station access control switch.
3. Radio Control - Three 2-wire serial output lines are provided for transferring command/control information to the SINCGARS-V radios.
4. Auxiliary Command Station - A 2-wire serial input is provided to accept radio command signals from an auxiliary command station.
5. XMIT Audio Module - Three 8-to-1 multiplexers provide for routing user voice signals to radio XMIT ports. A three bit station select word is strobed into the multiplexers by one of three separate radio XMIT select strobes.

Of the two circuit approaches considered for implementing these control I/O functions, the following advantages and disadvantages are considered in Table I.

The trade-off analysis in Table 3-IV clearly points out that the lower cost, smaller size and flexibility of a microprocessor control approach is the optimum method of control for the intercom system. The following paragraphs describe in some detail I/O and control approaches which will be implemented using a microprocessor. In the next reporting period the circuit details of a microprocessor control approach will be further developed along with the generation of flow diagrams which show command input responses. Functions to be controlled by a one chip microprocessor in the intercom system are summarized as follows:

Front Panel - Intercom control switches are binary coded. Refer to Figure 3-3. Microprocessor scans every 10 msec the following four switches: retransmit, radio access, enter, and external station. If the enter button was pressed the following switches are sampled to be stored for transmission to the radio: radio select, presets, RF power level, ECCM/normal, and CT/PT. Switches not used by the microprocessor are as follows: power, radio power, intercom accent, and commander's headset controls.

Table 3-IV. Discrete Versus Microprocessor Control Approach

Criteria	APPROACHES: Approach #1 Discrete I/O under discrete logic control	Approach #2 Discrete I/O combined with microprocessor data bus I/O & microprocessor control
1.Circuit complexity	1.Relatively simple gate, shift register and counter configurations can provide for the design of I/O and control functions.	1.Relatively simple microprocessor configurations consisting of a processor, RAM and ROM network can provide all control functions and several I/O functions. Discrete I/O circuits are provided where necessary.
2.Size	2. Although the complexity of the discrete design approach is relatively simple, the large number of gates and shift registers results in a very large control network.	2.The use of a one-chip microprocessor results in a very small physical size for the control network.
3.Cost	3. The large number of discrete control circuits results in high assembly cost during production.	3.The use of a microprocessor reduces assembly costs in production.
4.Flexibility	4. Changes in intercom control functions require modification of actual circuits and is costly.	4.Changes in intercom control functions can be accomplished through simple re-programming and is inexpensive.

SINCGARS-V Radios - When front panel control microprocessor sub-routine has indicated a change in radio operation the radio interface sub-routine is called. Radio update information is then formatted into a Universal Asynchrnous Receiver Transmitter (UART) format (i.e. start, stop, and parity bits are added). An external reference clock is then used to transmit information to SINCGARS-V radios. Microprocessor then looks for valid receive word back from radio. Operator will be alerted if an error should occur in transmission.

Radio transmit control involves three separate I/O ports. Referring to Figure 3-3, the microprocessor is informed of transmission requests by users through the TDM interface network. The microprocessor enables each TDM network, one at a time, to send its control bits over the control bit bus. The control bit bus is shared between all TDM networks. If there are any conflicts in requests, the microprocessor decides who has priority. Once informed of the request, the microprocessor strobes the XMIT audio module with the 3-bit station select word so as to connect the individual user audio with the radio. The third I/O port sends PTT information.

Auxiliary Commander's Control Station - When the auxiliary station is connected to the commander's station, a pin in grounded notifying the microprocessor to check the auxiliary serial port for a transmission from auxiliary control. If a transmission is received, then the controls are updated. If the microprocessor is not in the process of receiving a transmission from the auxiliary unit the front panel of the commander's station is scanned. If switches have been changed operator control is transferred back from the auxiliary to the commander's station. Transmission over the auxiliary serial link is in a digital UART format. This results in a reduction in software. The same UART subroutines used for SINCGARS-V radios can be used for the auxiliary link.

Alarms - At the present time ITT-A/OD is aware of one external alarm to be included into the vehicular intercom. It is not known whether this will be an analog tone or a digital signal with an alarm tone generated internal to the Intercom.

Logistic Support Analysis (LSA):

The Vehicular Intercom LSA conference was held at ITT-A/OD October 18, 1977, in accordance with the contract schedule. Those attending this conference were Glen Williman (Project Engineer - ECOM), Bruce Balance (LSA Representative - ECOM), John Heitz (Project Engineer and Program Manager - ITT-A/OD), and Bill Sloan (ILS Manager - ITT-A/OD).

The LSA Plan was updated to incorporate changes resulting from the LSA conference, and the revised plan submitted to ECOM November 8, 1977, in accordance with contract requirements (CDRL Item A003). The revised plan was reviewed and approved subject to incorporation of two changes. These changes were made and the revised plan resubmitted to ECOM December 16, 1977.

The LSAM ADP Program (GEMM) source deck and sample input data file were requested and received from ECOM in accordance with contract requirements. The program is installed on disc at our data processing support contractor, INSCO Corp., Neptune, N.J. Test programs will be run via phone line access using our SYCOR 340 I/O terminal next month.

Government furnished LSAM input data for card numbers 22, 27, and 31 through 42 were requested from ECOM November 1, 1977, as required by contract. These inputs have been received successfully tested.

Simplified engineering evaluation forms have been prepared for use in initial trade-off of design alternatives. A copy of the evaluation form (ITT FW PO-02) is included herein for ECOM review/comment. Data for two design alternatives are included on the evaluation form. The two alternatives are: 1) a time division multiplex (TDM) system and 2) a discrete signal distribution (DSD) system. The TDM system has been selected for LSA modeling using the Generatized Electronics Maintenance Model.

ITT AEROSPACE/OPTICAL DIVISION
FORT WAYNE, INDIANA

PRODUCT SUPPORT/LOGISTICS

EVALUATION SUMMARY - ALTERNATE DESIGN APPROACHES

ITEM	EVALUATION PARAMETER	WEIGHING FACTOR	ALT. A		ALT. B		ALT. C		REMARKS
			BASE RATE	SCORE	BASE RATE	SCORE	BASE RATE	SCORE	
1	COST - Life Cycle (R&D, Investment, O&M)	26	10	260	10	260			
2	PERFORMANCE - Flexibility, Security, Range, Survivability	15	10	150	9	135			Alt. A provides better noise immunity.
3	EFFECTIVENESS - A_o, MTBM, Mct, Mpt MMH/OH	13	10	130	9	117			More linear devices used in Alt. B.
4	DESIGN CHARACTERISTICS - Human factors, safety, producibility, interchangeability, commonality, power, weight, volume, accessibility, maint. skill requirements	10	10	100	10	100			
5	OPERABILITY - Simplicity of operation, operator training	9	10	90	10	90			
6	SPARES/REPAIR PARTS - Part type & quantity, standard parts, procurement time	8	10	80	10	80			
7	TEST AIDS - Test equipment, calibration standards, BITE, test points, tools, maint. tapes	6	10	60	10	60			
8	SCHEDULE - R and D, Production	6	10	60	[illegible]	60			
9	FLEXIBILITY/GROWTH POTENTIAL - Reconfiguration, design change acceptability	4	10	40	8	32			Alt. B requires more extensive mod to ddd capability.
10	DESIGN DATA - Design drawings, specifications, logistics provisioning data, tech manuals, reports	3	10	30	10	30			
SUB-TOTAL		— —	— —	1,000	— —	964	— —		
DERATING FACTOR (DEVELOPMENT RISK)		— —	— —	100	— —	145	— —		
GRAND TOTAL		100	— —	900	— —	819	— —		

ITT FW PS 02 11/77 (SHEET 1 of 2)

NOTES:

BASE RATE ____________ Values from 0 to 10 are applied according to the degree of compatibility with the desired goals. If the goals are met, a rating of 10 is assigned.

SCORE ____________ Multiply the base rating values by the weighting factors to obtain the score.

DERATING FACTOR _____ A special derating factor (a percent of the sub-total) is applied to each alternate to compensate for risk or uncertainty.

REMARKS ____________ Provides for comments that cannto be adequately weighted by the individual item scores. For example, if an alternate does not meet minimum PERFORMANCE requirements, it should be discarded even though its overall score may be higher than another alternate.

Mechanical (Intercom)

Mechanical design was emphasized during this first quarter. The primary mode of operation is collecting data and allowing the electrical engineers to establish more detailed electrical parameters. The following shows the basic path of the mechanical design and activities that are ongoing at this time.

The basic mechanical design philosophy has not been altered from the original vehicular intercommunication system proposal. Construction is basically cast aluminum boxes. This radio will be more compact, with greater abilities than existing models. Control panel design will have proper size and separation for logical use and it will be easy to use with gloves.

The internal parts of the radio are being designed to optimize maintainability. This is accomplished by having a front panel with all its elements (switches, lights, etc.) attached to a common circuit card. This assembly interconnects with the radio printed circuit (P.C.) card, and in turn, this card interconnects with the wiring harness. With this type of assembly the user needs only to remove the captive hardware on the front panel to remove the front panel and expose or remove the radio circuits.

During the next quarter, front panel layouts and simple mock-ups will be emphasized to get initial feel for operational factors aspect.

4.0 Statement of Work for Next Reporting Period

In continuation of the Intercom Program, the following areas will be developed further in the next quarter:

Applicable Technology Investigation

- The analysis of the wireless techniques will be completed in the next quarter. This will require analysis of the acoustic devices and comparing the acoustic system with the remaining wireless techniques.
- The TDM system will be developed in more detail and analysis will be made as to noise immunity of the system in an environment similar to trac ked vehicles. This analysis will be carried into breadboard testing toward the end of the second quarter and carry into the third quarter.
- Application of fiber optic link from crew station to commander's control station will be investigated. This analysis will include the problems in using the link for half duplex signaling. The fiber optic link will then be compared with the wireline analysis.

Implementation of Functional Requirements into System Design

Design of the commander's control station will be initiated. The mechanical portion of the design is especially important because this will give an indication of the complexity of the front panel which now has the external station control requirement. Electical design will follow and may not proceed past the block diagram stage until the third quarter.

4.3 LSA

The sample input data file will be inputed into the LSAM ADP program for testing. Data for the GEMM inputs will be generated for one or possibly two versions of the Intercom System. This data will be inputed into the LSAM program and the results will be reported in the GEMM report which will be completed in the second quarter.

APPENDIX A - I.R. Wireless Communication Link Analysis

In the proposal two types of I.R. wireless communication were discussed. These were a pulsed FM I.R. system and a pulse modulated TDM system. In each I.R. approach short duration pulses are modulated onto the I.R. light carrier. In the FM case the pulses are frequency modulated by the voice signal. In the TDM case digitized voice plus command signals are pulse modulated onto the light carrier. The following is a general analysis of a pulse modulated I.R. communication link. The results are applicable to both the FM or TDM pulse modulation formats. For pulse transmission systems, the optimum SNR at the receiver is provided when B (receiver 3 dB B.W.) = $.4/\tau$ where τ is pulse width. For an FM pulse modulated system, a carrier frequency of 100 kHz to 200 kHz is typical and the pulse width is between 50 usec and 25 usec. For a single channel TDM system discussed in Section 3.2 of this report the 240 KBPS data rate results in a pulse width of about 40 usec. A post detection SNR of at least 10 dB is rquired for effective FM demodulation and at least 17 dB is required to provide a 10^{-5} bit error rate for the TDM system.

The following analysis will show the performance of an I.R. link both inside and outside an army vehicle. It is shown that an I.R. can easily support the omni-directional transmission of narrow pulses at distances in excess of 3 meters inside the vehicle. The only constraint on such a link is the level of background light interference. For an external I.R. system omni-directional transmission at a range of 50 meters is shown to be unfeasible due to both path loss and the level of daylight interference.

A typical single emitter/single detector I.R. communication link is shown in Figure 1. Upon analysis of this link a more general I.R. array configuration for omni-directional communication will be described. In figure 1 a TIXL12 GAS I.R. emitting diode transmits TDM pulses and exhibits the following characteristics:

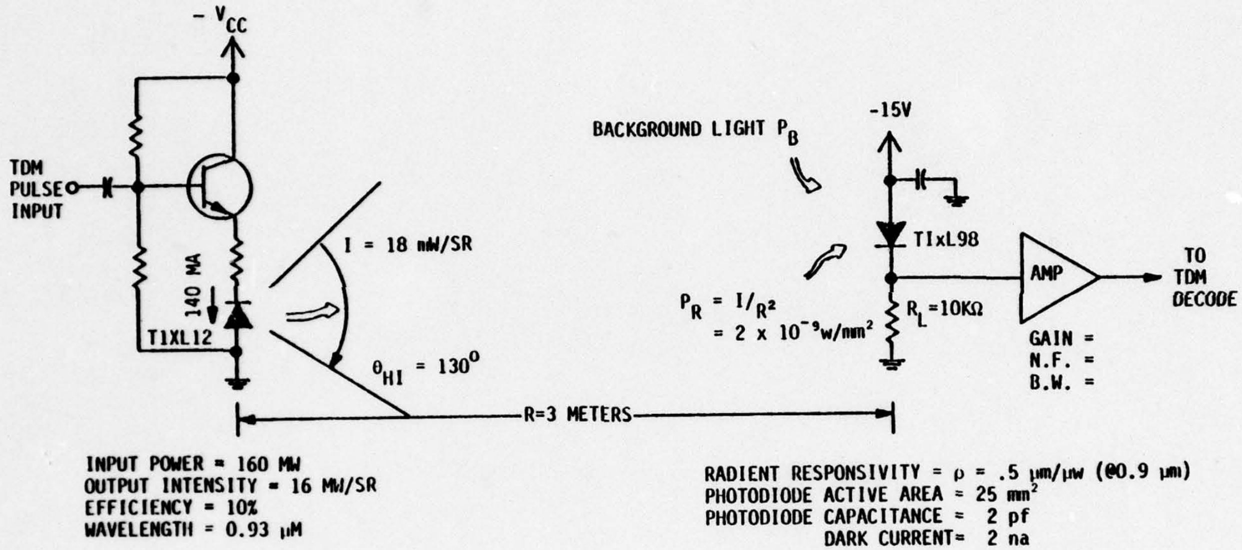


Figure A-1. Typical I.R. Communications Link

I_F (forward bias current = 140 ma

V_F (forward bias voltage) = 1.3 volts

Input power = Pin = 182 mW

Output intensity = I = 18 mw/steradian

Efficiency = 10%

Wavelength = 0.93 μm

Half intensity beam angle Θ_{HI} = 130^{o}

These parameters are further defined in figure 1. At the receiver, which is located 3 meters away, a TIXL98 photodiode is used to detect the I.R. TDM pulses. The characteristics of the receiver photodiode are listed as follows:

Radiant Responsivity = ρ = 0.5 μA/μw (@0.9 μm)
Photodiode Active Area = 25 mm^2
Capacitance = 2 pf
Dark current = I_d = 2 na

This communication link can now be analyzed as presented in the following equations.

(1) P_R (irradiance at receiver) $= I/_R2$ watts$/_M2$ $\quad I = 18$ mw/SR, $R = 3$ meters

$= 2 \times 10^{-3}$ watts/m^2
$= 2 \times 10^{-9}$ watts/mm^2

(2) P_S (received signal power) $= P_R \times A_d$ $\quad A_d$ = Photodiode active area = 25 mm^2

(3) P_d (detected signal power) $= [\rho \times P_S]^2 \times R_L$ $\quad = 0.5$ μA/μw

$= 6.25 \times 10^{-12}$ watts $\quad R_L$=10K selected to provide 1 mHz video bandwidth

(4) N_o (Received noise power due to load resistor) $= 2$ K TB $\quad k = 1.38 \times 10^{-23}$ Joules/K^o, $T = 290^o$ K

$= 8 \times 10^{-15}$ watts $\quad B = 1$ mHz

(5) N_o (internal diode noise power) $= 2\,eB\,(P_S + P_B + I_d)\,R_L$

$N_o = 3.2 \times 10^{-13} [25\times10^{-9} + P_B + 2\times10^{-9}] \times R_L$

$N_o = 8.0 \times 10^{-17} + .64\times10^{-17} + 3.2\times10^{-9} \times P_B$

$e = 1.6\times10^{-19}$ coulomb
$B = 1$ mHz
$R_L = 10$ K
$I_d = 2\times10^{-9}$ amps (dark current)
$P_S = 50\times10^{-9}$ watts
$P_B =$ background light received power

(6) SNR (detected SNR) =

$$= \frac{(\rho \times P_S)^2 \times R_L}{2eB(\ P_S + P_B + I_d)\ R_L + 2\ kTB}$$

$$= \frac{6.25 \times 10^{-12}}{(8.64 \times 10^{-17} + 3.2 \times 10^{-9} \times P_B) + 8\times10^{-15}}$$

From equation 6 it is seen that if $P_B \ll 10^{-5}$ watts the received SNR is

$$\text{SNR } (P_B \ll 10^{-5} \text{ watts}) = .77 \times 10^3 = +29 \text{ dB } ^*$$

If the background light irradiance which falls upon the diode active area results in a P_B power level which exceeds 10^{-5} watts, then the receiver detected SNR will be degraded and eventually becomes inoperable at P_B 10^{-4} watts. The following discussion analyzes the condition under which P_B approaches 10^{-4} watts. The received background light power is given by the following equation:

(7) $P_b = M \cdot A_d \cdot \beta_{opt}$

M = irradiance of background light
A_d = diode active area
β_{opt} = bandwidth of photodiode optical filter

In equation (7) and equation (2) above the percent transmission of any optical filter has been assumed to be 100% to simplify the present analysis.

In an army tank the level of background light is as yet unknown but is probably in large amount generated by incandescent lights. The use of tungsten filament incandescent lights presents the most severe interference problem, since almost all of the light's output power

is generated at I.R. For a 10 watt bulb the efficicacy (K) of the bulb is 7.9 lumens/watts and the output luminous flux is 79 lumens and the corresponding radiant flux is 10 watts. Most of all radiant power for a tungsten light bulb is dissipated at IR wavelengths about 1 μm. If a 10 watt tungsten lamp is considered a point source for analysis purposes, then the radiant intensity at 1.0 μm is 790 mw/steradian. The irradiance of a 10 watt bulb at three meters is then 85 mw/m^2 according to equation (1). The total power which falls on an area of 25 mm^2 is therefore 2.125×10^{-6} watts. Since the radiant intensity of the interfering light is at the same wavelength as the I.R. communication system, then the use of interference rejection filters at the I.R. detector will not reduce the interference. Also, it is noted that the power level of the interfering light is approaching the 10^{-4} watt limit specified in equation (6) above. The only solution to this problem is to reduce the level of interference by placing I.R. filters on all incandescent lamps and indicators within the tank.

Another solution to the I.R. interference problem is to investigate the use of emitter/detector networks in ultraviolet spectrum region if units which operate at this wavelength are available and operate at reasonable efficiencies. For the time being let us assume I.R. filters are used on interferring lights to reject interference. The reamining problem involves the design of an I.R. array to assure omnidirectional coverage by the transmitted signal within the vehicle.

If an I.R. wireless approach were possible for internal use and interference problems are solved, then the design of the emitter and detector arrays on the user's headset becomes very important. It is highly desirable to obtain omni-directional coverage with as few emitters as possible to conserve power for the wireless user. The design of the

* A post detection SNR of 29 dB is well in excess of the 17 dB required for a BER $<10^{-5}$ for a TDM system and also well in excess of the 10 dB SNR required for the pulsed FM I.R. link.

central transmitter/receiver array at the intercom commander's control station is less critical since power consumption is not a problem here. To illustrate possible emitter arrays, a possible arrangement of TIXL-12 diodes is shown in figure 2. In this arrangement, four transmitting diodes are required to provide hemispherical coverage. This arrangement could be reduced to 3 diodes to provide less overlap. The power dissipation when using four transmit diodes is calculated as follows. The power dissipation of each diode is 180 mw from figure 1. The duty cycle for a pulsed FM system is 50% and the average power dissipation of each diode is 90 mw. The duty cycle of the return link of a wireless TDM system is only about 17% and the power dissipation of each diode is 30 mw. If it is taken into consideration that the TDM modulation being used is 40 KBPS CVSD, then a logic 1 is transmitted only 50% of the time. This further reduces the duty cycle to 8.5% and the average diode power dissipation to 15 mw. The total average power dissipation for the 4 diodes is 360 mw in the pulse FM case and 60 mw in the TDM case. Since only 10 dB SNR is required at the receiver in the pulsed FM case versus 17 dB for the TDM case, the required output power for the FM case can be reduced by 7 dB which will result in an output transmit power for 4 diodes of about 72 mw. It is seen then that both wireless modulation techniques dissipate about the same average dc power level. If a VOX network is incorporated with the wireless headset, then this power dissipation is only incurred when voice traffic is taking place. A 60 mw transmitter power dissipation requirement is well within battery design requirements.

The key design risks and also critical design areas for a wireless I.R. system are summarized as follows:

1. A 1 MHz receiver noise bandwidth will easily support the SNR requirements of a TDM system at ranges in excess of 3 meters.
2. The average transmitter power consumption for a 4-diode array is 60 mw.
3. Interference due to I.R. emissions from incandescent lights can disable system operation.

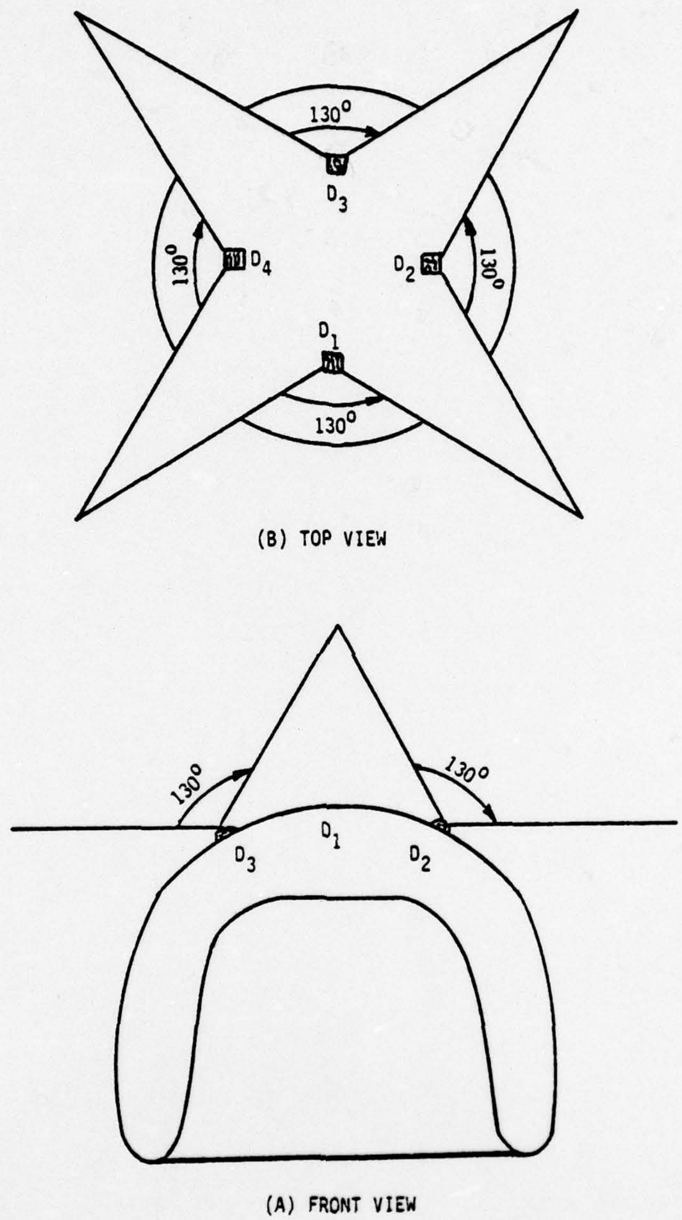


Figure A-2. I.R. Emitter Diode Locations on CVC Helmet

4. To reduce interference of incandescent lights, filters at each light bulb may be required.

The above analysis is only applicable to I.R. communications internal to the vehicle where ranges are on the order of 3 meters (max) and interference is due to incandescent lights which can be filtered.

External to the vehicle the level of background light interference increases, path losses increase at distances of 50 meters and detectability by the enemy becomes a problem. If equation (1) and (2) are applied to an I.R. link operating at 50 meters and it is desired to achieve the same signal power of 50×10^{-9} watts required in the previous design case for a range of 3 meters, then the required output intensity of the transmitting diodes is 5 watts/steradian. This high transmit intensity is obsiously not practical for the wireless communication system under consideration. The reason such a high output power is required is that omni-directional coverage must be provided at a range of 50 meters.

The other limiting factor in utilizing I.R. wireless techniques external to the vehicle is the presence of sunlight interference. Even on an overcast day the spectral incidence of sunlight is about 6 watts/m^2/µm at a wavelength of 1 umeter. The typical bandwidth of an I.R. receiver in terms of wavelength is about 0.4 umeter. The irradiance of the inteference reaching the detector is about 2.4 watts/m^2. This corresponds to an irradiance of 2.4×10^{-6} watts/m m^2. For a TIXL12 detector diode with an area of 25 mm^2, the detected power level at 1 um due to sunlight on an overcast day would be about 6×10^{-4} watts. This level of light interference would result in less than 0 dB SNR at the output of the detector diode. I.R. bandpass filters could reduce the level of interference to some degree, but it is pointed out that this analysis was performed for an overcast day. A bright, sunlit day would definitely render an I.R. wireless system inoperable. In summary, the use of an I.R. wireless communication link outside the vehicle is not possible:

1. Transmit intensity levels of 5 watts/steradian are impractical.

2. Sunlgiht interference renders system inoperable

3. Detection of I.R. signal by enemy renders system undesirable.

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This is the first quarterly report for the design study for a Vehicular Intercommunication System primarily for tracked vehicles. The report covers the time period from 29 September through 31 December 1977.
Accomplishments for the period included the establishment and documentation of functional, electrical and mechanical requirements for the vehicle commander and crew member stations. Preliminary tradeoff studies for techniques for wireless intercommunication for certain crew members were made. Results of initial investigations for control and signalling techniques are likewise included.

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